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SUMMARY PAGE

THE PROBLEM

The development of voice interactive computer systems (VIS) for the control of on-board aircraft systems is expected to result in reduced operator workload and increased effectiveness of naval aviation crews. A data base is needed to provide answers to human factors engineering questions arising from this development.

APPROACH

The research reported in sixteen major scientific journals, as well as in Psychological Abstracts, for the interval 1967-1977 inclusive, was examined for reports of investigations of human performance in concurrent verbal and continuous manual control tasks. A few readily available technical reports were also examined.

CONCLUSIONS

Adequate experimental data are not available to form a data base to support human factors requirements of the VIS development. A comprehensive research program is needed to determine the extent of human operator performance capabilities in timeshared verbal and manual control tasks.

INTRODUCTION

The control of military aviation systems frequently places severe demands on the operator to process information from two or more channels simultaneously. The requirement to maintain continuous control over a system while concurrently receiving or transmitting verbal communication is common to all aviation systems. Effective performance on simultaneous verbal and control tasks will become paramount in the next generation of military aircraft with the introduction of on-board computerized voice interactive systems (VIS) that have the capability to recognize and act upon spoken commands for the control of weapons and other systems. The development of voice interactive systems is expected to significantly reduce operator workload and increase the effectiveness of naval aviation crews. A data base is needed to provide answers to human factors questions arising from this VIS development. The present review of the research literature was undertaken to determine whether such a data base could be established.

Several researchers have investigated human performance in concurrent verbal and tracking, flying, or driving tasks. The material contained in this review represents a critical examination of this research reported during the interval 1967-1977 inclusive.

FIELD RESEARCH

A few studies were conducted during the 10 years to determine whether there is significant interference between communications and control tasks in either an operational or a training environment. For example, Nicholson (13) reported an experiment which demonstrated that communications during approach and landing can seriously affect pilot workload. Generally, such field experiments have shown decrements in performance on concurrent control and communications tasks. However, even the most well-planned efforts have encountered difficulties, leading to ambiguous results and tenuous conclusions. Goebel, Williamson, and Baum (10) reported a multitude of difficulties encountered during a preliminary experiment investigating the effects of radio communication on performance of a student during instrument training. The authors employed a ground based trainer rather than an aircraft for reasons of safety and because the ground trainer was capable of greater experimental control. In spite of extensive planning, the cooperation of instructors and students involved in the experiment, and the advantages of a ground based trainer, several problems arose during the experiment which bear directly on the interpretability of the data they obtained. These problems included nonstandardized practice sessions, inconsistent scoring of performance, subjects being eliminated due to poor performance, uncontrolled scheduling of subjects, and engineering problems in the apparatus, among others. In spite of such problems, the authors were able to reach a tentative conclusion that radio "chatter" may have some slight disruptive effect on performance during training.

Other researchers have noted similar problems in conducting field experiments, such as the difficulty of establishing control over relevant independent variables, and problems in instrumentation required to obtain data. (See Brown, (2); and Brown & Poulton, (3), for early work relevant here.)

LABORATORY RESEARCH

Several experiments have been reported in which laboratory tasks were employed to investigate the psychological processes operative during timeshared manual control and verbal information processing tasks. This research is discussed below, organized loosely by topic area.

TRACKING AND SHADOWING

The most elementary processes that are active during concurrent verbal and manual tasks involve simply input and output of information, with little transformation, reduction, storage, or other internal processing before responding. Cliff (6-8) reported an experiment in which subjects performed a zero-order compensatory tracking task concurrently with a verbal shadowing task. He selected these two tasks because they involve independent input and response modalities, so that any interference between the tasks could reasonably be attributed primarily to central effects rather than to physical limitations of the operators.

Cliff observed no decrement in performance with a narrow band forcing function on the tracking task and a slow shadowing rate, whereas a reliable decrement was obtained in both tracking and shadowing performance with a wide band forcing function and high shadowing rate. Examination of the tracking records of individual subjects revealed periods of apparent inactivity on the tracking task (called tracking holds) when verbal shadowing was performed concurrently. The distribution of verbal shadowing responses presented similar periods of no apparent verbal activity during dual task performance. A detailed analysis of these data suggested a model of the human operator as a continuous single channel monitor of the two input sources, switching attention to operate on verbal input when tracking error fell within some tolerable limit. Data generated by computer implementation of this model fit curves obtained from Cliff's subjects fairly well. However, because subjects performing a shadowing task typically evince little comprehension of the material being shadowed (5), the results obtained by Cliff are not readily generalized to more complex tasks that involve processing of the content of the verbal material.

TRACKING AND INFORMATION TRANSFORMING TASKS

Watson (18) employed a task devised by Baddeley (1) in conjunction with a compensatory tracking task to investigate the effects of the verbal task on derived pilot describing functions. The verbal problem required subjects to apply certain grammatical transforms to information presented aurally in order to make a binary response selection. Watson determined that although there was a decrement in tracking performance due to the secondary task demands early in the experiment, subjects improved with time until there appeared to be no appreciable effect at the end of the experiment. Error on the concurrent verbal task was almost zero.

In an earlier experiment by Brown, Tickner, and Simmonds (4), Baddeley's task was employed to investigate the effects of communication via radio telephone on automobile driving. They concluded that the communications task apparently affected judgements of clearance between barricades set up on a driving course, but did not seriously degrade a subject's ability to drive through a gap between barricades once the decision was made to try. The results of Watson's experiment seem to be consistent with those of Brown et al. Contrary to Watson's results, however, Brown et al. found that both speed and accuracy of performance on the verbal task were impaired in the dual task condition. It may be that the differential effects of a simple tracking task and automobile driving upon the same verbal task are related to fundamental attention demanding characteristics of these two tracking tasks. Alternatively, it may be that subjects in the two experiments allocated different priorities to the control tasks for reasons unrelated to their relative processing requirements. The experimental data are insufficient to address the question.

TRACKING AND MEMORY TASKS

Johnston, Greenberg, Fisher, and Martin (11) performed a series of experiments to assess the effects of different verbal encoding, retention, and recall tasks on performance of the same continuous compensatory tracking task. They observed that the recall task produced the greatest decrement in simultaneous tracking performance when compared to performance of tracking alone, and inferred that recall requires more processing capacity than either verbal encoding or retention.

The result that encoding and retention tasks interfere with tracking conflicts with evidence reported by Trumbo and his coworkers (14, 17). The results of five experiments suggested to Trumbo et al. that interference caused by performance of a verbal anticipatory learning task during pursuit tracking was due to the requirement to make an overt verbal response. Subjects who performed the learning task without verbal responding failed to show a decrement in concurrent tracking. The authors stated that "information from two channels can be processed simultaneously and efficiently, provided that one input is effectively stored for overt response at a later time." Trumbo and Milone (16) addressed the discrepancy between the results of Johnston et al. and Trumbo et al. in two experiments employing the same pursuit tracking task and the same verbal task. They concluded that response selection and/or execution required a greater proportion of available processing capacity than stimulus encoding or retention, but encoding and retention may be sufficiently demanding of attention that they interfere with tracking.

Mc Leod (12) suggested that the conclusion of Noble et al. (14) that encoding and retention of verbal material do not interfere with tracking was incorrect. He re-examined the reported data and found evidence that subjects who were supposed to attend to and learn verbally presented information without verbal anticipation apparently had failed to learn the material. Mc Leod conducted an experiment combining a tracking task with a secondary auditory-verbal task designed to more accurately measure performance of subjects processing verbal material without overt verbal responding. His results indicated that attention required to process auditory material without responding may be sufficient to interfere with tracking. This agrees with the conclusions of Johnston et al. (11) and Trumbo and Milone (16). Mc Leod noted, however, that the discrepancy between his results and those of Noble et al. (14) may be due to aspects of the experiments which are task specific. Further research is needed to resolve this issue.

Zeitlin and Finkelman (20-22) employed two different digit-processing tasks to investigate the operator loading effects of zero- and first-order control system dynamics. Their experiments were based upon the single-channel model of the human operator (19). According to this model, the operator is viewed as an information processing device capable of doing several tasks at once, as long as the total amount of information to be processed does not exceed the limited capacity of the system. If the amount of information to be processed exceeds system capacity, performance of one or more of the tasks is degraded. Zeitlin and Finkelman instructed their subjects to maintain performance on the compensatory tracking task at the expense of the digit-processing task, if necessary. They reported two main results. First, tracking performance (measured as time on target) with a zero-order system was better than performance with a first-order system, and was unaffected by concurrent digit-processing performance. Second, the two digit-processing tasks, a delayed digit recall task and a random digit generation task, differed in their sensitivity to interference due to the concurrent tracking task. The random-digit generation task showed no effect of the two alternative tracking systems. This result was consistent across all three studies. The delayed digit recall task (22) reliably differentiated between alternative control systems, showing less interference from the zero-order than from the first-order system. Zeitlin and Finkelman recommended that the delayed digit recall task be employed in a variety of settings to obtain estimates of operator loading.

Finkelman and Glass (8) employed the delayed digit recall task in conjunction with a compensatory step-function tracking task to study the effects of predictable and unpredictable auditory noise on dual-task performance. In this experiment tracking performance was unaffected by 9-second bursts of 80-dB auditory white noise. The effect of noise on delayed digit recall was small and probably unreliable in a single-task condition. In a dual-task condition, randomly scheduled noise bursts were more detrimental to delayed digit recall than was noise occurring at regular intervals. Finkelman and Glass concluded that the introduction of noise in the dual-task condition caused an overload of the subject's channel capacity, resulting in the performance decrement. However, it is uncertain whether the differential effects of noise on tracking and digit processing were due to the instructions to their subjects to give tracking priority, or to the specific structure of the auditory digit-processing task, making it more susceptible to interference from auditory noise.

Pew (15) reported an experiment conducted by Pew and Wickens to investigate the effects of extensive practice on pursuit tracking of predictable and unpredictable forcing functions. Their subjects tracked a random-appearing signal during several one-minute trials on each of sixteen days. Although the signal appeared to be continuous and unpredictable from the subject's point of view, one 20-second segment of each trial was always the same, except for certain control trials. The subjects exhibited differentially improved tracking performance for the repeated segment with extended practice. However, the subjects were either unaware of or unable to accurately describe the predictable character of the signal.

To further assess the nature of this unusual practice effect, Pew and Wickens required subjects to perform an experimenter-paced delayed word recall task concurrently with tracking on days 6, 11, 12, and 16. The results indicated a seemingly paradoxical effect. Tracking performance during the repeated (predictable) segment, which had shown differential improvement with practice presumably because it was becoming more "automated," actually exhibited a greater decrement due to concurrent performance demands. Pew (15) concluded that "whatever the subjects learned in this experiment appears to require sustained attention for its effects to be manifest." The subjects apparently paid more attention to the repeated segment, as reflected in the decrement in dual-task performance, but were unaware of the unique character of that segment. A replication of this result was not found in the literature.

CONCLUSIONS

It is clear that performance of some verbal tasks interferes with simultaneous performance of some tracking (control) tasks. It may be that the requirement to generate a verbal response during tracking is the greatest source of the interference. It is not at all clear what other characteristics of verbal tasks may interfere with tracking. Moreover, it is probable that certain parameters of the control task will be important determinants of any decrement in performance observed during simultaneous verbal information processing.

It is apparent that adequate experimental data are not available to form a data base to support human factors engineering requirements of the VIS development. The above conclusions are too general in nature to serve as guidelines for answering engineering questions. A comprehensive, systematic research program is needed to determine the extent of human operator performance capabilities in simultaneous verbal and manual control task.

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